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PRELIMINARY AIRBORNE MEASUREMENTS FOR THE SR-71 SONIC BOOM PROPAGATION EXPERIMENT

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ABSTRACT

SR-71 sonic boom signatures were measured to validate sonic boom propagation prediction codes. An SR-71 aircraft generated sonic booms from Mach 1.25 to Mach 1.6, at altitudes of 31,000 to 48,000 ft, and at various gross weights. An F-16XL aircraft measured the SR-71 near-field shock waves from close to the aircraft to more than 8,000 ft below, gathering 105 signatures. A YO-3A aircraft measured the SR-71 sonic booms from 21,000 to 38,000 ft below, recording 17 passes. The sonic booms at ground level and atmospheric data were recorded for each flight. Data analysis is underway. Preliminary results show that shock wave patterns and coalescence vary with SR-71 gross weight, Mach number, and altitude. For example, noncoalesced shock wave signatures were measured by the YO-3A at 21,000 ft below the SR-71 aircraft while at a low gross weight, Mach 1.25, and 31,000-ft altitude. This paper describes the design and execution of the flight research experiment. Instrumentation and flight maneuvers of the SR-71, F-16XL, and YO-3A aircraft and sample sonic boom signatures are included.

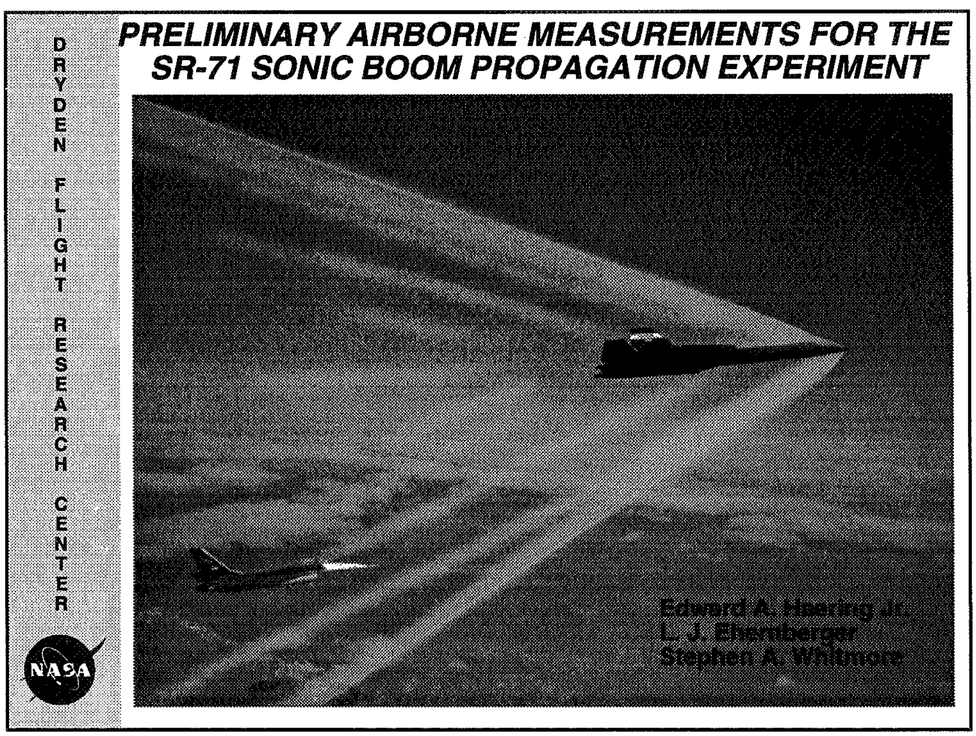

Figure 1

Propagation of sonic booms through the atmosphere has been studied for decades. Many of these studies involved measuring of the sonic booms at ground level; however, limited flight data has been gathered in the region where the shock waves begin to coalesce and before they attain the N-wave shape (Mullens, 1956, Smith, 1960, and Maglieri, 1963). The Sonic Boom Integrated Technology Development Team of the High Speed Research Program required a detailed database of sonic boom propagation flight data, concentrating on the non-N-wave region, to validate and refine sonic boom propagation prediction codes. These sonic boom propagation prediction codes would then be used to design and assess the environmental impact of the High Speed Civil Transport. Figure 2 lists objectives of the SR-71 Sonic Boom Propagation Experiment. The SR-71 was manufactured by Lockheed Aircraft, Burbank, California. The development of this flight test technique was used in the planning for the Tu-144LL (Tupolev Design Bureau, Moscow, Russia) Sonic Boom Signature Experiment.

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Experiment Objectives

- **Determine propagation characteristics of non-N-waves through a real atmosphere including the effects of Mach number and altitude on coalescence rate. Use this flight database to validate and refine propagation codes and analytic techniques.**

- **Provide a database to compare to Tu-144LL Sonic Boom Signature Experiment, and gain experience to enhance that test.**

Figure 2

The near field of a supersonic aircraft can be very complex because of the three-dimensional nature of the flow around the vehicle. Sonic boom signatures measured beneath and to the sides of the aircraft show the shocks and expansions generated by the various components and varying lift distribution of the aircraft. It would be convenient if these near-field pressure signatures could be extrapolated through the atmosphere all the way to the ground and provide predictions of sonic boom noise levels. Because current extrapolation methods are based on two-dimensional, cylindrical propagation models, they are best applied beginning at a minimum separation distance where the complex, three-dimensional flow disturbances around the aircraft have become cylindrical or quasi-cylindrical waves. At present, no generally agreed upon method for defining this minimum separation distance exists. Preliminary analysis suggests that distances of 7 to 10 span lengths or 5 body lengths may be sufficient. The SR-71 aircraft is 104 ft long, not including the noseboom, and has a wingspan of 56 ft; therefore, this paper reports signatures measured at distances greater than 520 ft, which is 5 body lengths or nearly 10 span lengths.

This paper presents the design and execution of the SR-71 Sonic Boom Propagation Experiment conducted at the National Aeronautics and Space Administration, Dryden Flight Research Center, Edwards, California. Flight maneuvers and instrumentation of the SR-71, F-16XL (General Dynamics, Ft. Worth, Texas), and YO-3A (Lockheed Corporation, Burbank, California) aircraft are included. Several auxilliary ground and flight tests are also discussed to validate the quality of the airborne instrumentation used. A sampling of the airborne data recorded from 540 to 21,000 ft below the SR-71 aircraft is presented. Descriptions of the ground-level sensors and measurements have been reported (Norris, 1995).

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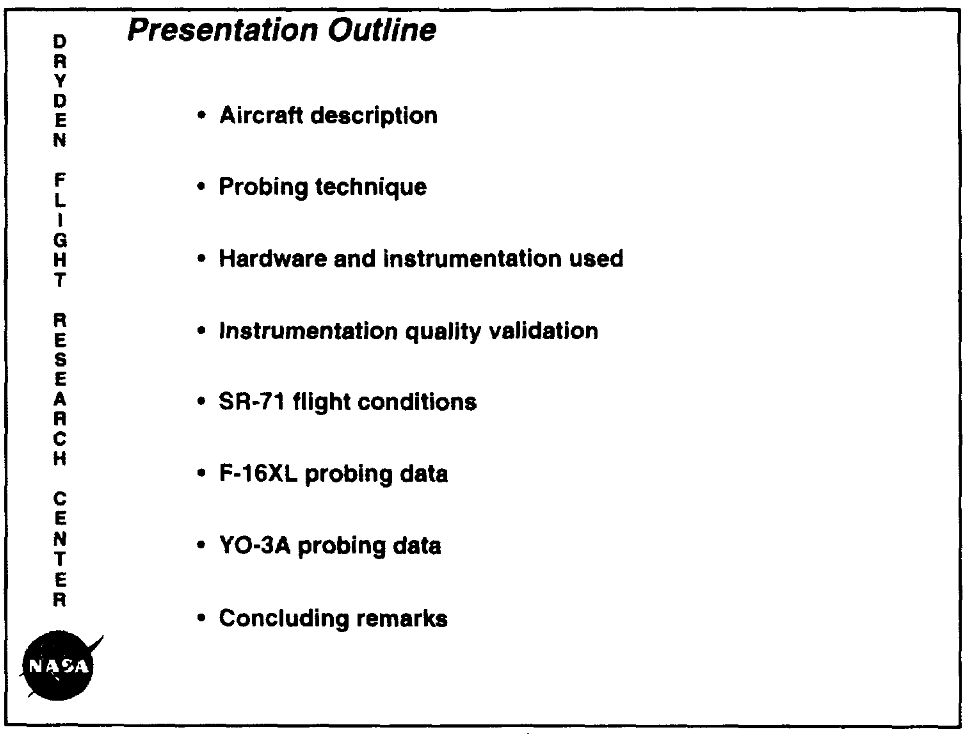

Figure 3

Figure 4 shows the three research aircraft used for this experiment: an SR-71, an F-16XL, and a YO-3A. A large sonic boom generating aircraft is desirable because it better approximates a High Speed Civil Transport, and it allows a more detailed spatial resolution of its shock waves. The SR-71 aircraft was selected as the sonic-boom-generating aircraft because of its large size and supersonic endurance. The SR-71 aircraft was flown from Mach 1.25 to Mach 1.6, altitudes from 31,000 to 48,000 ft, and gross weights from 73,000 to 118,000 lbf in steady, level flight.

Using a probing aircraft that could match the speed of the SR-71 aircraft was important for two reasons. First, having a small difference in speed maximizes the data collected during each probing and increases spatial resolution of the shock waves. Second, an increased number of probings can be taken if the probing aircraft has the ability to maintain a close proximity to the SR-71 aircraft. The F-16XL aircraft was used as the near-field probing aircraft because of its ability to keep in formation with the SR-71 up to Mach 1.5. In addition, the cranked delta wing design allowed for greater supersonic endurance than the majority of supersonic fighter type aircraft. The SR-71 aircraft has greater supersonic endurance than the F-16XL aircraft, so aerial refueling of the F-16XL aircraft was performed to maximize data collection on a single flight. The F-16XL was equipped with special pressure instrumentation in and behind its flight test noseboom.

Sonic boom predictions had shown that some of the SR-71 flight conditions planned could result in noncoalesced sonic boom signatures on the ground. These predictions assumed a quiescent atmosphere. A turbulent atmospheric layer near the ground might severely distort these signatures. Because this turbulent atmospheric layer may extend several thousand feet above ground level, it was important to record the sonic boom signatures above this layer to provide undistorted data of the noncoalesced sonic boom signatures. The slow-speed YO-3A aircraft was flown at an altitude of 10,000 ft to record the sonic booms above the turbulent atmospheric layer. The F-16XL aircraft could not probe to such a low altitude at supersonic speeds because of aircraft and airspace limitations. The YO-3A aircraft is typically used at the NASA Ames Research Center, Mountain View, California, to measure the acoustics of helicopters in flight (Cross, 1984), but its quiet and slow flight characteristics made it an excellent airborne platform for sonic boom recordings.

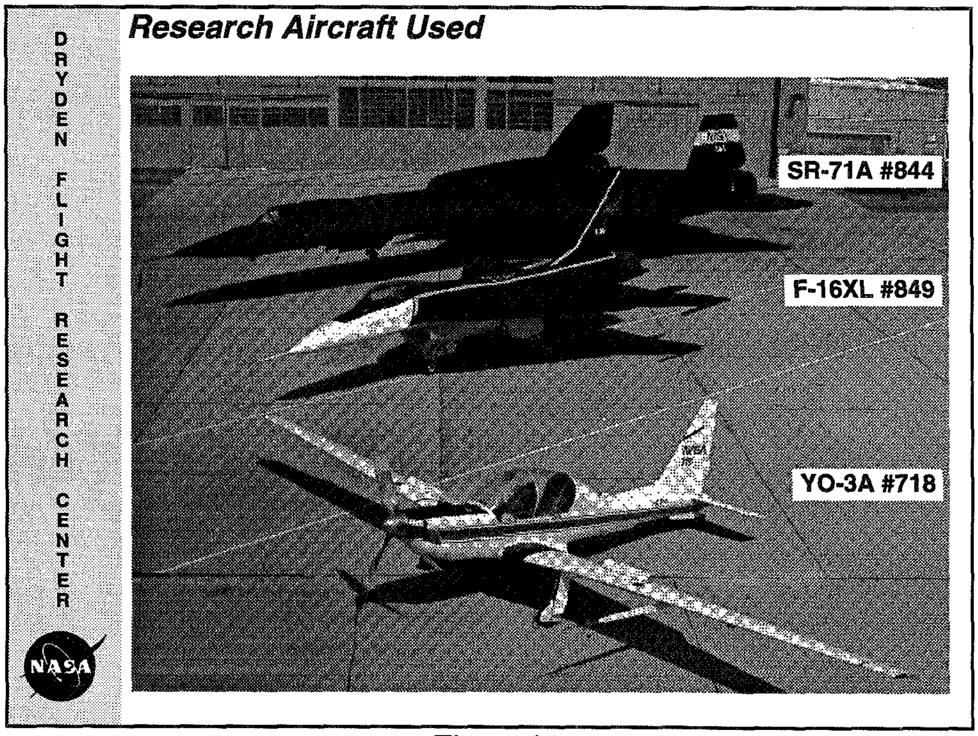

Figure 4

Figure 5 shows the path of the F-16XL aircraft during one probing of the SR-71 shock waves. The F-16XL aircraft would start behind the SR-71 tail shock and move forward, ahead of the bow shock. Then, the F-16XL aircraft would slow down to repeat the probing backward from the bow shock past the tail shock. Because the shock waves sweep behind the SR-71, longitudinal separation occurred between the tail of the SR-71 aircraft and the nose of the F-16XL aircraft during the probings. These probings were attempted to hold in level flight with no lateral offset from the SR-71 aircraft. While some of the probings gathered are quite level with very little lateral offset, most signatures have some variability in altitude and lateral offset.

When the F-16XL aircraft probed within 1000 ft of the SR-71 aircraft, its pilot had several indications of crossing the shock waves. These indications include feeling the pressure changes within the cockpit, being slightly jostled by the shock waves, and hearing the SR-71 engines when aft of the tail shock. When probings were conducted at vertical separations greater than about 1000 ft, the pilot was unaware when the shock waves were penetrated. Pressure and temperature data from the SR-71 and F-16XL aircraft were recorded on the vehicles and transmitted to the control room in real time. The pressure data from the F-16XL aircraft was displayed real time in the control room on stripcharts and computer plots. The pilot was then advised when he was ahead or behind the shock system of the SR-71 aircraft.

The YO-3A aircraft flew along the predetermined SR-71 flight track at an altitude of 10,000 ft and about 65 kn airspeed uptrack of the ground array of sonic boom recorders (Norris, 1995). The sonic boom signatures were recorded by the YO-3A aircraft as the SR-71 aircraft passed overhead.

In the cylindrical wave region, the F-16XL aircraft measured the SR-71 near-field shock to more than 8000 ft below the SR-71 aircraft and gathered 105 signatures during 7 flights. The YO-3A aircraft measured the SR-71 sonic booms from 21,000 to 38,000 ft below the SR-71 aircraft and recorded 17 passes. An array of several types of ground-based sonic boom recorders was used to complete the data set of sonic boom propagations, and 172 signatures were recorded (Norris, 1995). Atmospheric data were gathered for flight data analysis and for sonic boom propagation prediction codes (Ehernberger, 1992).

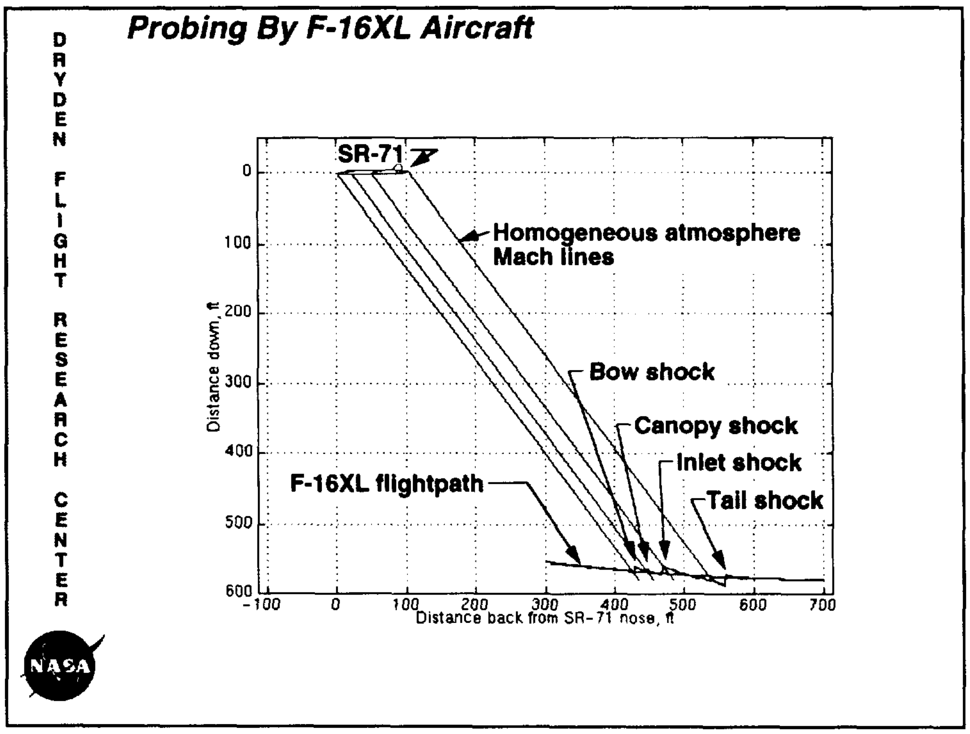

Figure 5

This SR-71 aircraft was equipped with research instrumentation (fig. 6). These instruments are used to measure the raw parameters needed for the flight conditions of the SR-71. A flight research quality airdata calibration will be determined during the final data analysis. Additionally, all SR-71 aircraft have a mission recording system, MRS. The MRS records many aircraft parameters once every 3 sec for use by the maintainence crew and aircrew after a flight. Even though MRS data are of a slow rate and low resolution, they are of great value because of the wide range of parameters recorded, especially parameters for the engines. The total fuel weight from the MRS will be used to give an improved measurement of angle of attack and lift coefficient.

The primary positioning and velocity data for this experiment were measured with the differentially corrected carrier phase Global Positioning System, GPS. Because the GPS data were not available during the flights, ground-based radar data (Haering, 1995) were used in real-time control room displays and as a backup for the GPS data. A radar beacon is installed in the SR-71 aircraft to enhance the quality of the radar data.

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SR-71 Instrumentation

- **Research instrumentation**
  - **Total pressure**
  - **Static pressure**
  - **Angle of attack**
  - **Angle of sideslip**
  - **Total temperature**
  - **Inertial navigation system**
  - **Accelerometers**
  - **Rate gyros**
- **Mission Recording System (MRS)**
  - **Low resolution, 3 sec/sample**
  - **Mach number, altitude, attitude, location**
  - **Engine parameters**
  - **Total fuel weight**
- **Differential carrier phase Global Positioning System (GPS)**
- **Radar beacon**

Figure 6

The primary instrumentation for this experiment was the pressure instrumentation installed in the F-16XL aircraft (fig. 7). The overpressures of the SR-71 shock waves were measured using four independent systems.

The first system measured the pressure difference between P1 and P2, which is called dp2 (fig. 7). The flush ports at location P1 were two holes ±37.5° from the top of the noseboom manifolded together. The ports at P2 have the same orientation as those at P1. This orientation was used to minimize variations in pressure because of angle-of-attack changes (Ritchie, 1959). The P1 ports were connected to the front side of the transducer using the shortest tubing possible. The back, or reference, side of the transducer was plumbed to the flush ports at P2, but with a reference tank, T, in between. This arrangement made this system essentially a very sensitive rate of descent sensor.

The second system measured the pressure difference between P3 and P2, which is called dp1. The flush ports located at P3 were two holes ±90° from the top of the noseboom manifolded together and were intended to minimize noseboom reflection factor effects.

The transducers used to measure dp1 and dp2 were identical highly accurate ±1 psi transducers sampled at 200 samples/sec. The reference tank was sized to give maximum lag without overranging the transducers during aircraft climbs and descents. The pressure of the tank, PR, and tank temperature was measured. Heater blankets were installed around these transducers to minimize calibration shifts because of temperature changes in the radome.

The third system used an absolute digital pressure transducer to record the indicated static pressure, Psi. This transducer was plumbed into the aircraft static pressure line close to the noseboom. The fourth and last system measured indicated total pressure, Pti, using an absolute digital pressure transducer plumbed into the aircraft total pressure line close to the noseboom. The transducers used to measure Psi and Pti were identical zero to 19 psi 16-bit digital pressure transducers. These transducers did not need heater blankets because they had internal temperature calibration compensation. The effects of aircraft speed and altitude changes on Psi and Pti will be removed using trajectory reconstruction to give shock wave overpressures.

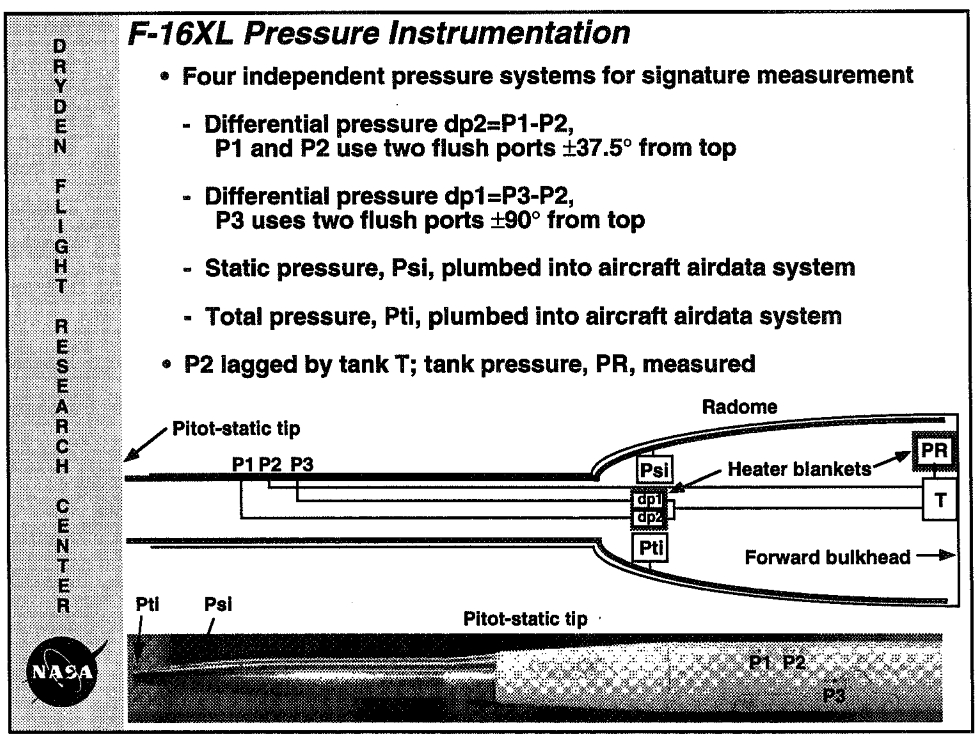

Figure 7

To ensure the quality of the pressure instrumentation aboard the F-16XL aircraft, special tests beyond normal calibrations were conducted on the ground and in flight. These tests were inspired by some of the challenges described in a B-58 (General Dynamics, Fort Worth, TX) experiment (Maglieri, 1963). Because the noseboom probe used in the B-58 experiment was quite long and thin, noseboom vibration affected the pressure data gathered. A noseboom ground vibration test was performed on the F-16XL aircraft to determine the natural vibration frequencies. Analysis of this vibration test is pending, but the pressure data measured in flight does not seem to show effects from noseboom vibration.

Another ground-based test involved applying step pressure inputs into each of the pressure port arrays. The front side of the differential pressure transducers showed no perceptible lag during these tests. Because the total and static pressure lines ran to the cockpit instrumentation and the airdata computer, large lag and attenuation were present. Pressure deconvolution techniques will be used with the pressure step responses to remove the lag and attenuation effects from the total and static pressures. The reference tank also had large lag by design.

There was some concern that the orientation of the flush ports to the incident shock wave would affect the overpressure values. Probing data below the SR-71 aircraft showed that the ±37.5° ports gave the same overpressures as the ±90° ports when the F-16XL aircraft was steady in pitch and yaw. The two sets of ports also gave the same overpressures when probing data were gathered to the side of the SR-71 aircraft. As a result for steady flight, the orientation of the ports to the incident shock wave had no effect on the data.

These ports were affected by changes in the pitch and yaw dynamics of the F-16XL aircraft. While the F-16XL aircraft was supersonic but not probing the SR-71, pitch and yaw sweeps were performed. The ±90° ports gave pressure variations with pitch changes. Because slight pitch changes occur in the F-16XL aircraft when probing below the SR-71 aircraft, the overpressure data using the ±90° ports are slightly affected. The ±37.5° port pressures were steady during pitch changes, but these pressures were affected by yaw changes. Because yaw remains steady while probing below the SR-71 aircraft, the ±37.5° ports give better pressure data than the ±90° ports.

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F-16XL Pressure Instrumentation Tests

- **F-16XL noseboom ground vibration test**
- **Pneumatic step response test**
  - **Differential pressure lines have no perceptible lag**
  - **Pitot and static pressure lag analysis pending**
- **SR-71 shocks measured to side and from below**

  ±37.5° ports give same results as ±90° ports
- **F-16XL supersonic pitch and yaw sweeps**
  - **±90° ports, dp1, affected by pitch, pitch changes when probing below SR-71**
  - **±37.5° ports, dp2, affected by yaw, not excited when probing below SR-71**

Figure 8

Shock wave pressures can be amplified by the shape of the sonic boom probe used. The ratio of the measured overpressure to the actual overpressure is called the reflection factor. On the B-58 experiment (Maglieri, 1963), one sensor on the noseboom probe had reflection factors of 1.07 to 1.23. These reflection factors were determined using wind tunnel tests. The reflection factors for the F-16XL aircraft will be determined later by comparing the pressures from the four independent measurement systems. This comparison will rely on the success of the total and static pressure deconvolution analysis. If this analysis is unsuccessful, a wind tunnel test of the F-16XL noseboom configuration may be needed to determine the reflection factors.

Another test to address F-16XL reflection factors was conducted using the sonic boom from an F-18 aircraft. The F-16XL aircraft was stationary on the ground with its instrumentation system operational. Several Portable Automatic Triggering System, PATS, sonic boom recorders (Norris, 1995) were placed with their pressure sensors at the same height and a few feet to the side of the F-16XL noseboom. An F-18 aircraft (McDonnell Douglas, St. Louis, MO) was flown at Mach 1.20 and an altitude of 30,000 ft. The F-16XL aircraft and the PATS recorders measured the sonic boom (fig. 9). The pressure data from both differential pressure transducers on the F-16XL aircraft compare favorably to the PATS units, so from this test the F-16XL reflection factor is 1.0. Whether the reflection factor for the F-16XL is significantly different while at supersonic speeds is unknown.

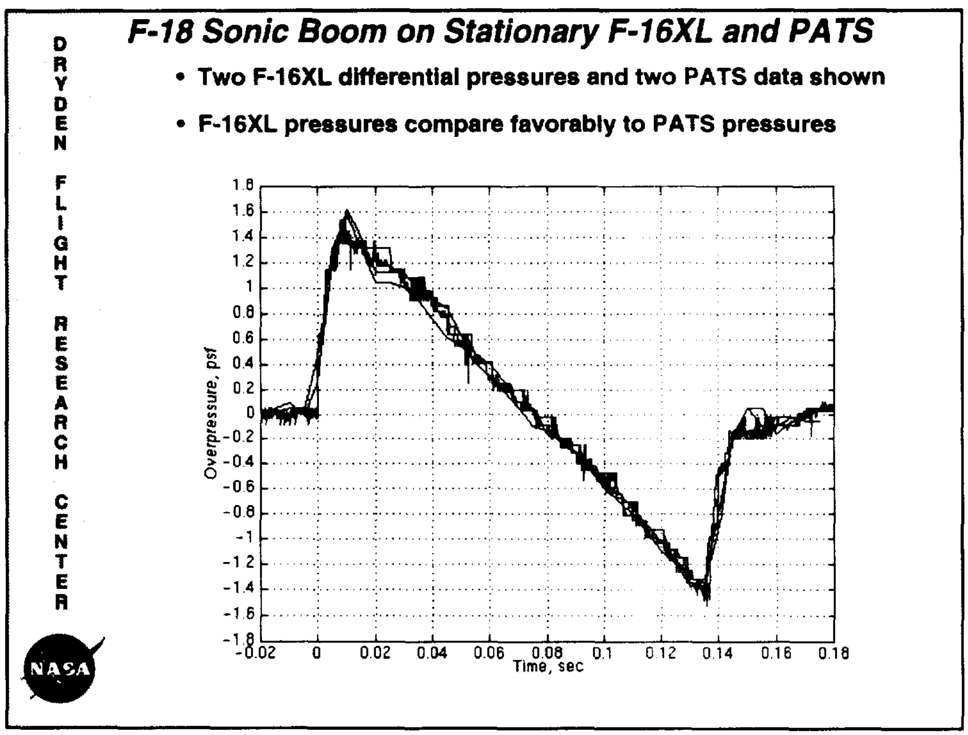

Figure 9

The primary instrumentation of the YO-3A aircraft consists of three microphones mounted on each wingtip and the top of the vertical tail (fig. 10). Each microphone element was protected within a cone-shaped housing that minimized noise caused by the forward motion of the aircraft. The aircraft was designed to be extremely quiet in flight, in part, because of a long muffler that runs the length of the fuselage and a specially designed low-speed propeller.

In addition to the three microphones, airspeed, altitude, ambient temperature, angle of attack, angle of sideslip, voice, and time were recorded in analog on a FM tape recorder (Cross, 1984). The airspeeds of the YO-3A and SR-71 aircraft will be used to transform the time-based sonic boom signatures into overpressures in terms of length. Before this test and each flight, a calibration signal of 123.8 dB and 251.8 Hz was applied to each of the microphones. This calibration signal allows conversion of the recorded microphone voltage into overpressure.

A handheld coarse acquisition, C/A, code GPS receiver was used to establish the position of the YO-3A aircraft when a sonic boom was detected. The sonic booms were not heard aboard the YO-3A aircraft, but an oscilloscope monitoring the microphone signals and the pilot's vertical speed indicator indicated sonic boom passage.

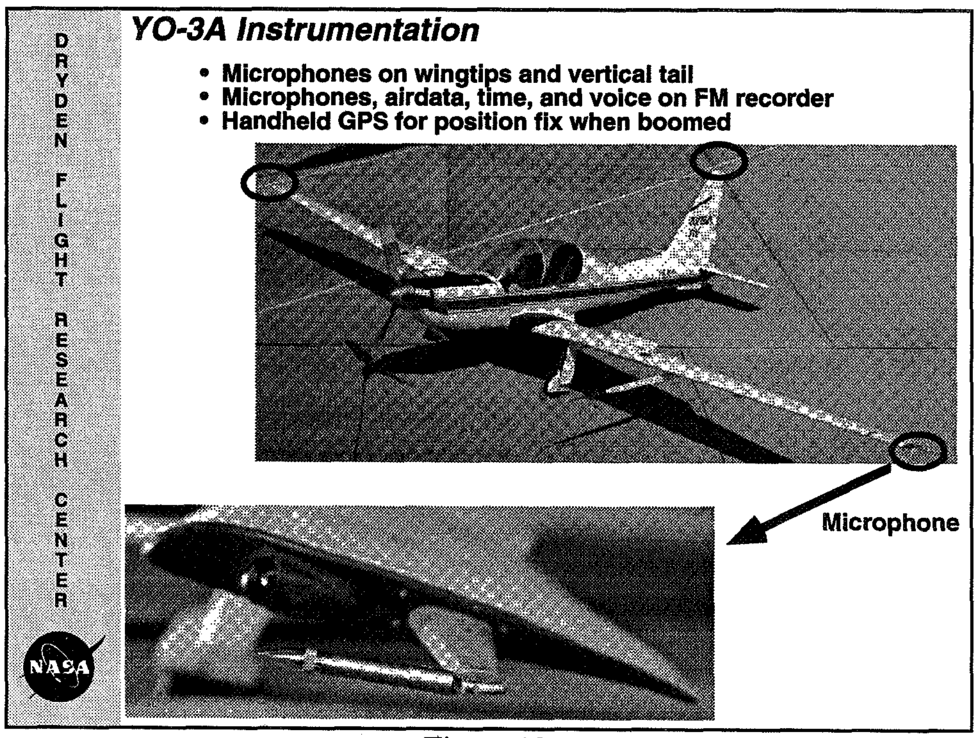

Figure 10

A reflection factor test for the YO-3A aircraft was conducted in the same manner as for the F-16XL aircraft. A sonic boom from an F-18 aircraft was recorded by the stationary YO-3A aircraft, a PATS, and a Small Airborne Sonic Boom Recorder, SABER, located near the microphones (Norris, 1995). These data have not been digitized for analysis, but stripchart playback of the analog microphone signals shows these data to have been high passed filtered. This filtering gives the bowed shape to the ordinarily straight diagonal pressure drop of an N-wave (fig. 11). The YO-3A microphones have demonstated flat response to as low as 2 Hz, but these microphones are filtered at some lower frequency. In spite of this, the separation distance between shocks, the pressure rises of each shock, and their rise times were adequately recorded.

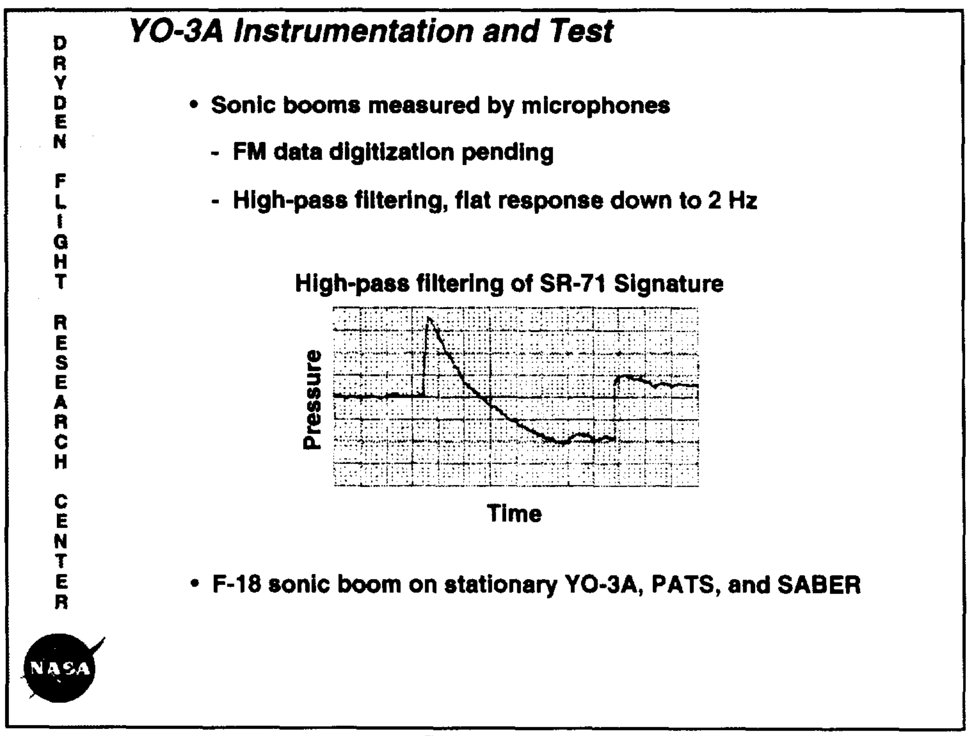

Figure 11

Pressure data gives one part of the propagation information (fig. 7). The remaining parts needed are the location where those pressures were recorded relative to the SR-71 aircraft, and the relative speed of the SR-71 aircraft to the F-16XL aircraft. Also, the position of the SR-71 relative to the ground-level sonic boom recorders is needed. Differentially corrected carrier phase GPS data were selected to determine these positions and speeds because its accuracy is superior to ground-based radar and cine-theodolite data, especially over the vast distances required to conduct high-speed flight research. The Z-12 GPS receivers (Ashtech, Sunnyvale, CA) were located in the SR-71, the F-16XL, and at a ground station to provide differential corrections. The Z-12 units were also used to survey the locations of the ground-level sonic boom recorders (Norris, 1995). Each airborne unit recorded its own data, and these data were downloaded after each flight. The sample rate of the GPS receivers was set to 1 sample/sec to allow about 4.5 hr of recording time. Data from each airborne unit were then processed with the ground station data to give the differentially corrected data.

Several tests were conducted to assess both the absolute position accuracy and the accuracy of the separation between the two airborne GPS units. On one flight, the SR-71 and F-16XL aircraft were flown side by side at subsonic speeds while being videotaped from an F-18 aircraft which was flying below these aircraft. Using the span and length of both vehicles to judge scale, the relative separation was determined from the videotape. The separation distance data from the video images and the GPS agree to within ±10 ft. A portion of this difference may result from parallax and optical distortion of the F-18 canopy.

On another flight, the SR-71 aircraft was tracked by cine-theodolite during two approaches to the runway. The absolute position data from the cine-theodolite and GPS agree to within ±2 ft. The velocities agree to within ±1 fps, which is the accuracy of the cine-theodolite.

For the last test, two GPS units were placed in an automobile, with the unit antennas mounted on a board 7 ft, 8 in. apart and then driven up to 80 mph. The GPS data showed that the relative separation of the antennas was correct to within ±0.5 ft, and the velocities of the two receivers agreed to ±1.0 fps. This agreement indicates that GPS data are an excellent source for aircraft relative separation measurements.

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Differential Carrier Phase GPS

- **Allowed accurate position and velocity over large test area**
- **Ashtech Z-12 differential carrier phase GPS used:**
  - **Onboard SR-71**
  - **Onboard F-16XL**
  - **Ground station**
  - **Survey ground sensor locations**
- **Data recorded within receiver, 1 sample/sec, differentially corrected postflight**
- **GPS accuracy assessed**
  - **Video images from chase aircraft: ±10 ft**
  - **Cine-theodolite data: ±2 ft, ±1 fps**
  - **Automobile test with known separation: ±0.5 ft, ±1.0 fps**

Figure 12

For this experiment, the SR-71 aircraft flew in level, stabilized flight. Figure 13 shows the flight conditions. The test points at Mach 1.25, an altitude of 31,000 ft, and low gross weight were intended to allow noncoalesced signatures to propagate down to the ground. Flying at the same Mach number but at 44,000 ft allowed altitude effects on the propagation to be seen. A third group of test points were flown at Mach 1.48 and an altitude of 48,000 ft to show Mach number effects on propagation. A few additional test points were gathered at other conditions. Data gathering was attemped at Mach 1.6, but the F-16XL aircraft could achieve that Mach number only very slowly. Only one data point was collected. Other probings occurred while the SR-71 aircraft was accelerating to one of the three main flight conditions. The YO-3A aircraft also gathered data at the same flight conditions as the SR-71 aircraft.

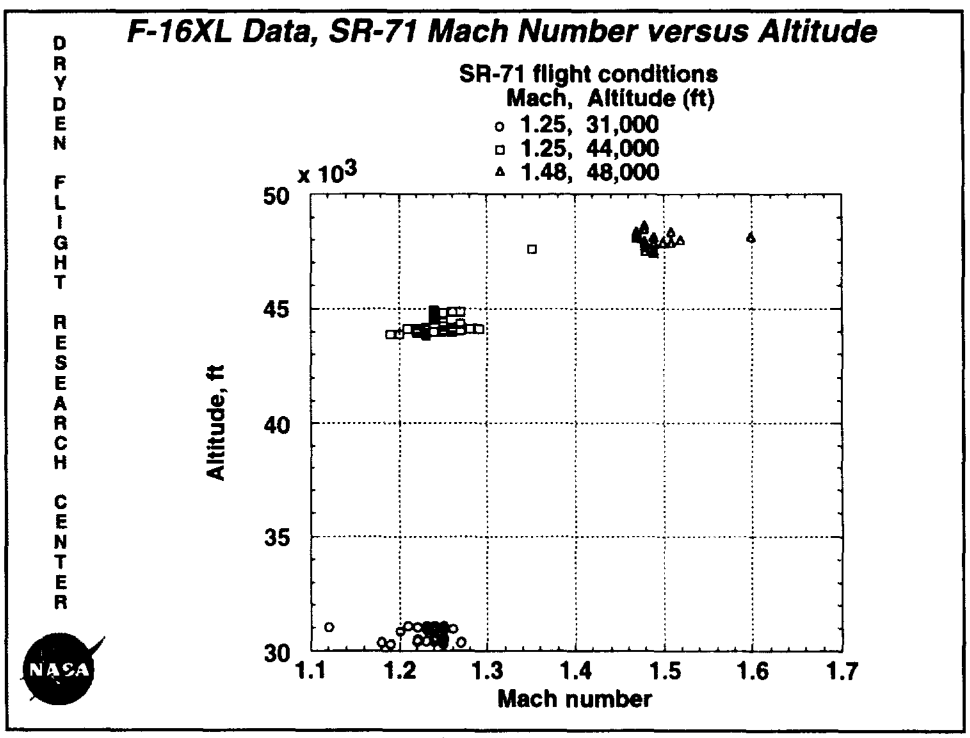

Figure 13

Figure 14 shows the F-16XL aircraft probed the SR-71 shock waves at several vertical separations, and signatures are available at these conditions. The F-16XL aircraft probed more than 8,000 ft below while the SR-71 aircraft was at Mach 1.25 and 31,000-ft altitude; more than 6,000 ft below while the SR-71 was at Mach 1.25 and 44,000-ft altitude; and more than 4,000 ft below while the SR-71 was at Mach 1.48 and 48,000 ft altitude. In addition, because the YO-3A aircraft was recording at 10,000-ft altitude, vertical separations of 21,000, 34,000, and 38,000 ft were achieved for these three SR-71 flight conditions. The data that are shown closer than 540 ft vertical separation had an additional lateral offset component. Because of normal fuel usage on the SR-71 aircraft, these data cover a range of gross weights and, therefore, lift coefficients.

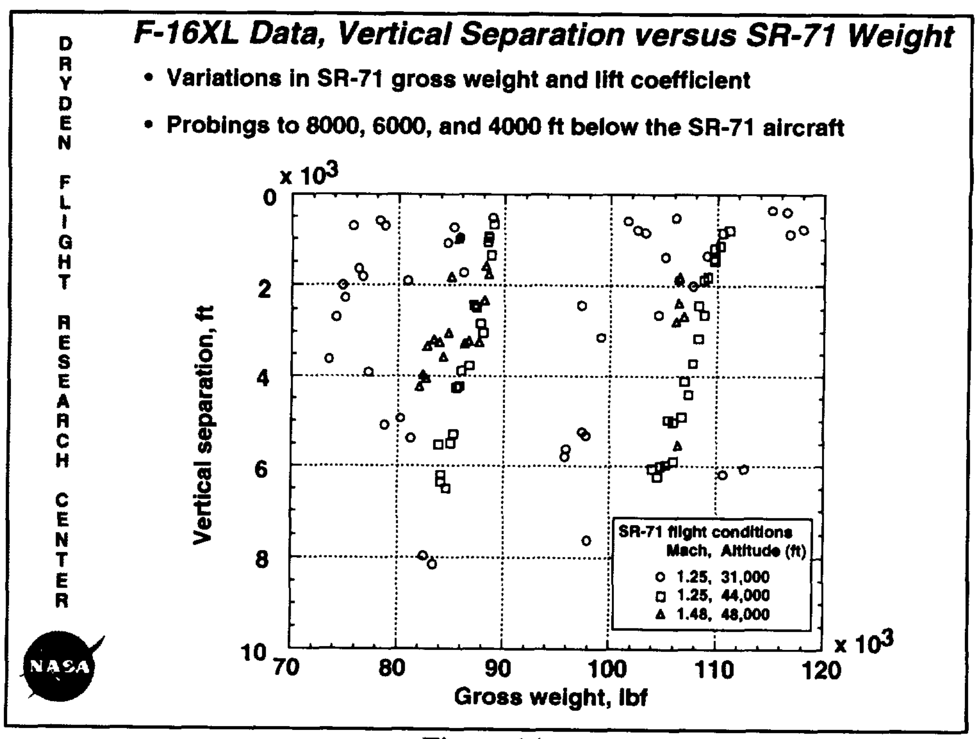

Figure 14

Figure 15 shows vertical separation as a function of maximum overpressure for the 105 probings. These data are preliminary because a reflection factor is not yet known, and other data corrections are still needed. The expected trend of decreasing maximum overpressure with increasing vertical separation is seen. Theory, wind tunnel, and other flight data show that overpressure should be a function of separation to the -3/4 power (Carlson, 1962), and these data confirm this relationship. Also, the lower altitude SR-71 data have the higher maximum overpressures. Some of the scatter in these data may be attributed to varying lateral offsets and SR-71 gross weight changes between data points.

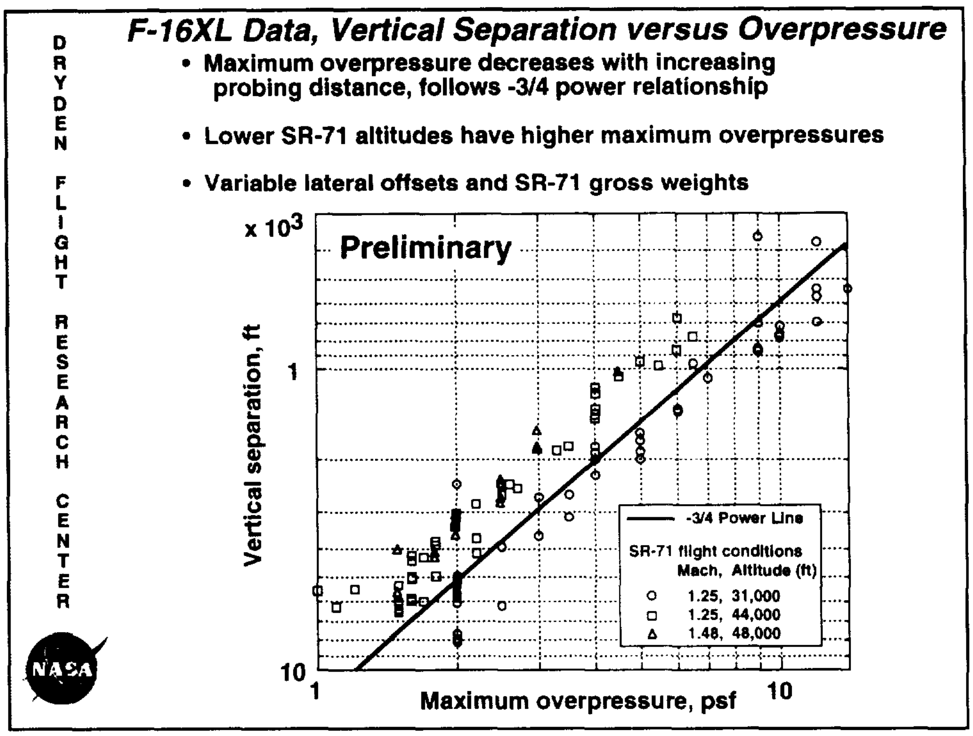

Figure 15

Figure 16 shows sonic boom signatures from the SR-71 aircraft at Mach 1.25 and an altitude of 31,000 ft with 540- to 7,980-ft vertical separation. These data are also preliminary because of the unknown reflection factor, and an estimate was used for the mean pressure line. Because the differential pressure systems act as rate of descent sensors, future analysis will be needed to calculate rate of descent from GPS and weather data to give a more nearly accurate mean pressure line.

As expected, several trends can be noted in figure 16. As vertical separation increases, the overall signature length increases, the overpressures decrease, and the inlet and canopy shocks move toward the bow shock. One interesting and unexpected trend concerns the plume pressures aft of the tail shock. All of the plumes from each signature collapse to one curve.

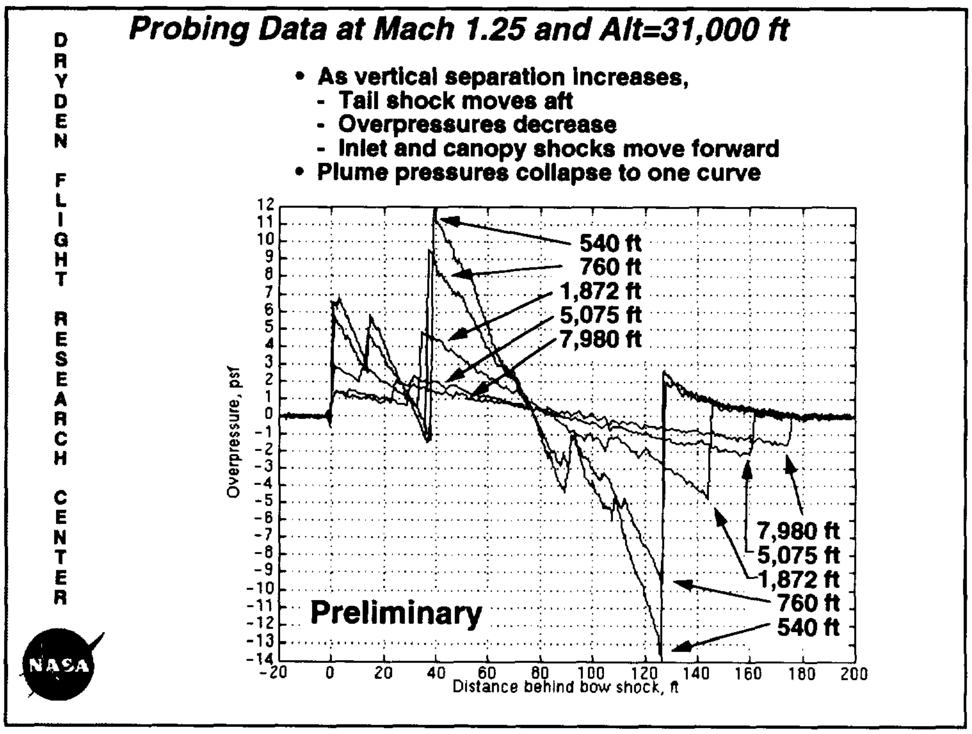

Figure 16

Figure 17 shows sample probing data for SR-71 flight conditions of Mach 1.25 at an altitude of 44,000 ft with 680- to 6,000-ft vertical separation. Again, the data follow the same trends as seen at Mach 1.25 and an altitude of 31,000 ft.

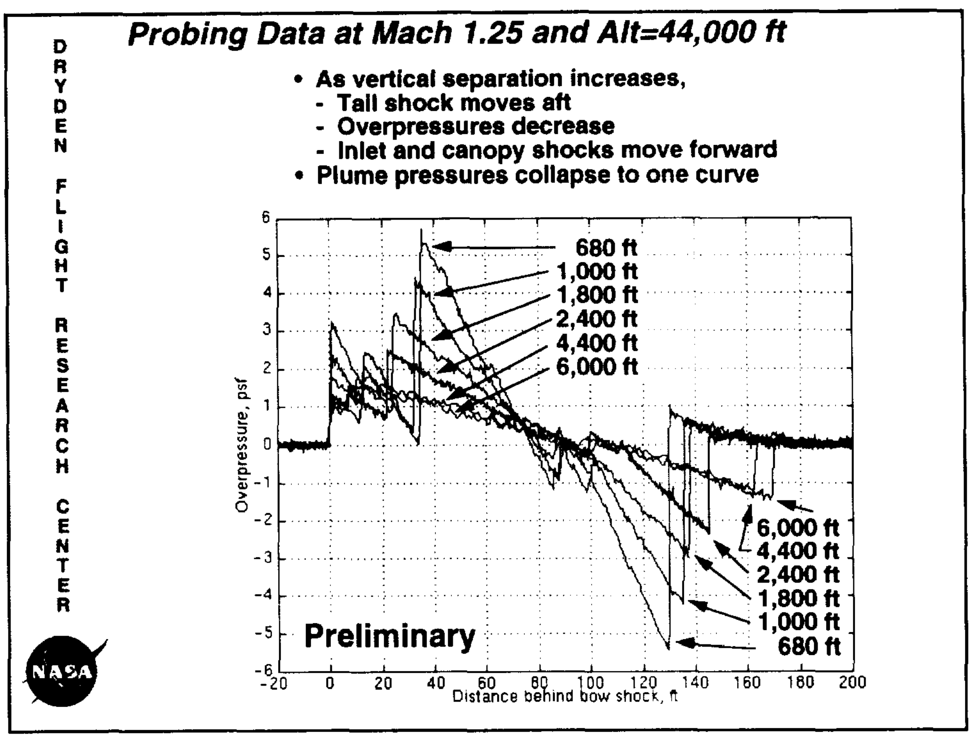

Figure 17

Sonic boom signatures from the SR-71 at a Mach 1.48 and at an altitude of 48,000 ft with 1,000- to 3,370-ft vertical separation follow the same trends as the two data sets shown in figures 16 and 17 (fig. 18).

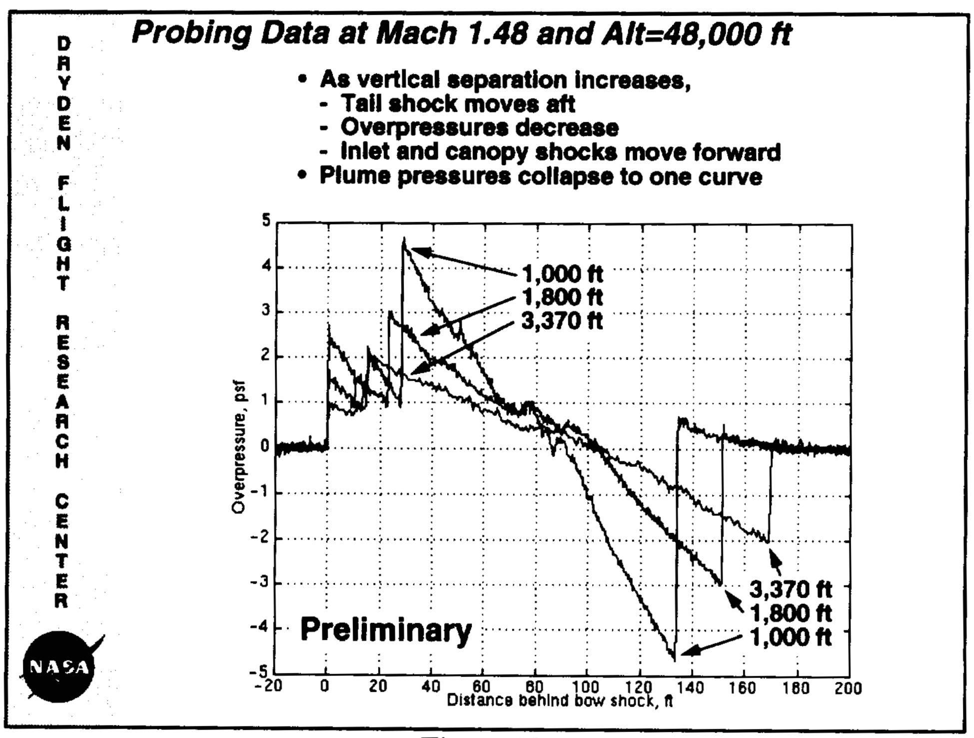

Figure 18

Figure 19 shows the distance of each major shock wave as a function of vertical separation for the three flight conditions. Four trends can be seen in these data. First, the tail shock is farther aft at Mach 1.48, the highest Mach number flown, than at Mach 1.25. Second, the canopy and inlet shocks travel forward slowest for an SR-71 altitude of 31,000 ft, the lowest altitude flown. Third, the canopy and inlet shocks coalesce for Mach 1.48. Fourth, the bow and canopy shocks coalesce for Mach 1.25.

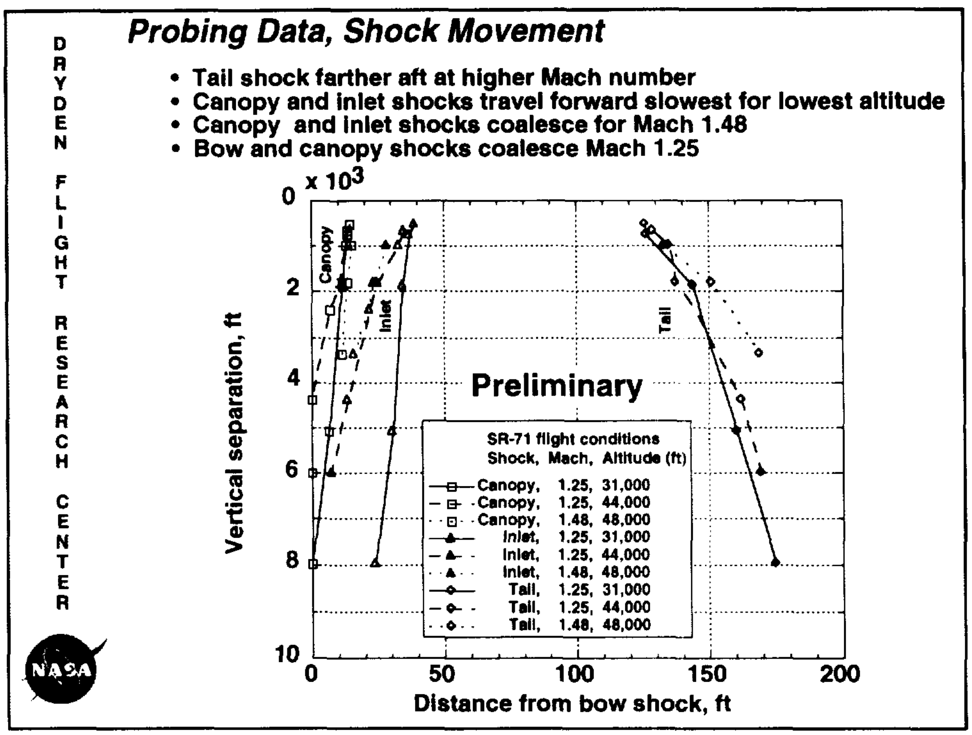

Figure 19

Figure 20 shows the overpressures of each major shock wave as a function of vertical separation for the three flight conditions. Here tail overpressure is expressed as a positive number. These overpressures are the peak value of each shock from the zero pressure line of the entire signature, not the pressure rise within the shock. Again, the attenuation rate follows the -3/4 power relationship. These pressure data fall into three groupings. In the first group, the tail and inlet shock waves from an SR-71 altitude of 31,000 ft, the lowest SR-71 altitude flown, have the highest overpressure. A second grouping occurs with the bow and canopy shocks when the SR-71 flys at altitudes from 44,000 to 48,000 ft. These shocks have the lowest overpressures. The remaining shock waves are in an intermediate overpressure group.

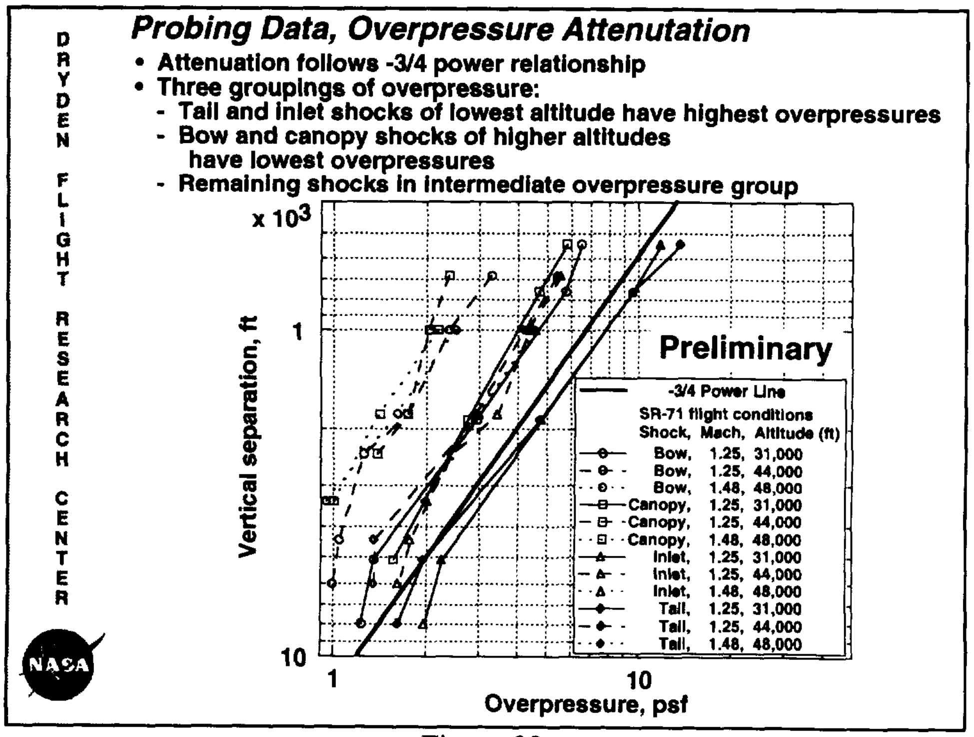

Figure 20

Figure 21 shows sample SR-71 sonic boom signatures recorded by the YO-3A. These data were gathered with the SR-71 aircraft flying at Mach 1.25 and an altitude of 31,000 ft during three passes on one flight, and the gross weight of the SR-71 decreased with each pass. The YO-3A was flown at an altitude of 10,000 ft for all the flights. The bowed expansion in each signature shows the high-pass filtering of the data. As expected, the maximum overpressure decreases as the gross weight of the SR-71 aircraft decreases. The heaviest weight pass shows a coalesced bow and inlet shock. The medium and lightest weight passes show separation between the bow and inlet shocks, with the separation increasing with decreasing SR-71 gross weight. The corresponding ground signatures from this flight were all coalesced N-waves (Norris, 1995).

In addition, the YO-3A aircraft measured the signatures from the supersonic F-16XL aircraft. Some of the recorded sonic booms from the SR-71 and F-16XL aircraft had reflected off the ground and propagated up to the YO-3A. The reflected shocks would have traveled twice through the lower level of the atmosphere. These data are being reduced.

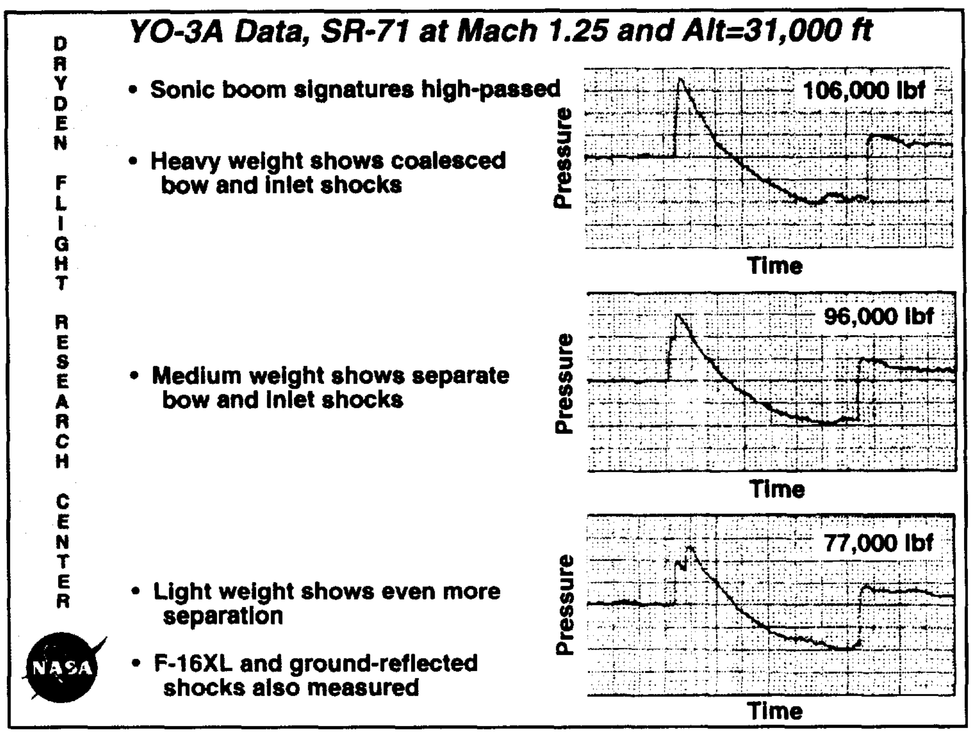

Figure 21

Three aircraft were used for the SR-71 Sonic Boom Experiment: the SR-71 as the sonic boom generator; the F-16XL as the supersonic probing aircraft; and the YO-3A as the far-field, slow speed microphone platform. These aircraft used flight research quality instrumentation systems, including specialized pressure sensors on the F-16XL and differential carrier phase GPS on the SR-71 and F-16XL. These instruments underwent several ground and airborne calibration tests to assess their accuracies.

The SR-71 was flown at three flight conditions to assess the effects of Mach number and altitude on sonic boom propagation. The F-16XL probed the sonic boom signatures at nearly the same speed as the SR-71, while the YO-3A was overflown by the SR-71. Seven flights gathered 105 F-16XL probings, 17 passes of the YO-3A sensors, and 172 ground-recorded signatures (Norris, 1995). These data are spatially dense signatures of high fidelity and will give the sonic boom community an opportunity to fully validate sonic boom propagation codes for the flight conditions flown.

Preliminary data from this experiment was shown in figures 13 through 21. Shock location and overpressures are affected by Mach number, altitude, and aircraft gross weight. The analysis of these data is ongoing. Plans include releasing the full database with all corrections to the sonic boom community.

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Concluding Remarks

- **Flight test technique described**
  - **Three aircraft used: SR-71, F-16XL, and YO-3A**
  - **Specialized, high accuracy instrumentation**
    - **Four independent pressure measurements on F-16XL**
    - **DGPS on SR-71 and F-16XL, sub-foot accuracy**
    - **Microphones on YO-3A**
    - **Several ground and flight instrumentation tests conducted**
  - **SR-71 flown at three flight conditions**
  - **Probing technique described**
  - **Large data set collected during seven flights**
    - **105 F-16XL probings**
    - **17 YO-3A passes**
    - **172 ground-recorded signatures**
- **Preliminary data shows Mach number, altitude, and gross weight effects on sonic boom propagation**
- **Analysis of data ongoing for release to sonic boom sommunity**

Figure 22

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